EFFECT OF CORROSION ON PRINTED CIRCUIT BOARD

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ABSTRACT

Corrosion of electronic systems has been a significant issue in electronic industry nowadays. One of the most common corrosion type is the atmospheric corrosion. Therefore, even a small environmental impact can cause huge damages if the components are not well protected. When the device is in use, the large voltage gradients between points on a printed circuit board (PCBs) will accelerate the corrosion problems dramatically. The complexity of the atmosphere, as corrosion environment, results from atmosphere composition and from presence of some factors as pollutants, temperature, humidity, wind speed and direction. So, the objective of the study is to identify the effect of corrosion on solder joint and copper substrate in 0.5M Sulphuric acid (H_2S0_4) in order to determine the corrosion rate of the substrate in duration time by using weight loss measurement method. Lead-free solder bump were used to form solder joint between lead-free solder Sn-3Ag-0.5Cu (SAC 305) solders with the plated copper substrate. The copper substrate surface finish was deposited by the electroless nickel. The result of study shows the corrosion on the substrate after immersed in 0.5M Sulphuric acid at 168 hours, 336 hours, and 504 hours. The effect of corrosion was increased with the time duration increased. The weight loss data indicated that the thickness of the substrate decreased with the time duration. The structure of the solder joint was analyze using scanning electron microscopy (SEM).

ABSTRAK

Kakisan sistem elektronik telah menjadi isu yang penting. Salah satu jenis yang paling kerap mengalami kakisan adalah kakisan atmosfera. Oleh itu, walaupun kesan yang kecil alam sekitar boleh menyebabkan kerosakan yang besar jika komponen-komponen tidak dilindungi dengan baik. Apabila peranti yang digunakan, kecerunan voltan yang besar antara titik pada PCB akan mempercepatkan masalah hakisan secara mendadak. Kerumitan atmosfera, persekitaran kakisan, hasil daripada komposisi atmosfera dan dari kehadiran beberapa faktor seperti pencemaran, suhu, kelembapan, kelajuan angin dan arah. Oleh itu, objektif kajian ini adalah untuk mengenal pasti kesan hakisan pada sendi pateri dan kepingan tembaga dalam asid sulfurik 0.5M (H_2S0_4) untuk menentukan kadar kakisan kepingan tembaga dalam tempoh masa yang ditetapkan dengan menggunakan kaedah pengukuran berat kepingan tembaga yang hilang. Bebola pateri plumbum telah digunakan untuk membentuk sendi pateri antara tembaga Sn-3Ag-0.5Cu (SAC 305) dengan kepingan tembaga bersalut. Kemasan permukaan kepingan tembaga telah disalut oleh nikel tanpa elektrik. Hasil kajian menunjukkan hakisan pada kepingan tembaga selepas di rendam dalam 0.5M asid sulfurik pada tempoh 168 jam, 336 jam dan 504 jam. Kesan hakisan meningkat dengan peningkatan tempoh masa. Data berat kepingan tembaga menunjukkan penurunan ketebalan kepingan tembaga dalam tempoh masa dan menganalisis struktur sendi pateri dengan menggunakan mikroskop imbasan elektron (SEM).

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF THE PROJECT

In recent years, corrosion of electronic systems has been a significant issue in electronic industry nowadays. Multiplicity of materials used is one reason of limiting the corrosion reliability. The reduced spacing between components on a printed circuit board (PCB) due to miniaturization of device is another factor that has made easy for interaction of components in corrosive environments. Presently the knowledge on corrosion issues of electronics is very limited. Simultaneously, increased use of electronics has also increased the demand for reliability. The demand for miniaturization, multiplicity of materials used, effect of process residues together with unpredictable user environment has opened up serious corrosion problems. Therefore, even a small environmental impact can cause huge damages if the components are not well protected. When the device is in use, the large voltage gradients between points on a PCB will accelerate the corrosion problems dramatically. However, the impact of voltage gradient on PCB corrosion is often overlooked with respect to damage in electronic circuits. The atmospheric conditions for corrosion are very complex and the corrosion rates vary in function of geographic zone, of season and daily time. The complexity of the atmosphere, as corrosion environment, results from atmosphere composition and from presence of some factors as pollutants, temperature, humidity, wind speed and direction, etc.

1.2 PROBLEM STATEMENT

The purposed of this research is to identify the effect of corrosion between the solder joint and the copper board with electroless nickel surface finish in 0.5M Sulphuric acid by using weight loss measurement with scanning electron microscopy (SEM). By using this method, the formation of structure in the joining can be analyzed and can identify the life time of the material and joining used in the electronic device especially PCB that very popular in electronic gadgets especially smart phones among the consumers. Unfortunately the electronic device such as phones will not last longer and the life of these gadgets also became questioned when exposed to different kind of environment such as sea water and sulfur environment. They have several type of corrosion that happened in electronic system (PCB). Several materials are used in electronic industry and new materials are emerging all the time. However, the materials combinations together with demand for miniaturization and large spread in user environment have introduced significant corrosion problems.

1.3 OBJECTIVES OF RESEARCH

Basically, the main purposes in accomplishing this study are shown below :

(i) To investigate the effect of corrosion at the joining of the lead-free solder Sn-3Ag-0.5Cu (SAC 305) and electroless nickel surface finish of the copper board.

(ii) To study the suitable method for the experiment and to calculate the corrosion rate for each specimen by using formula.

1.4 SCOPE OF RESEARCH

Scopes of this research, lead-free solder bump were used to form solder joint between lead-free solder Sn-3Ag-0.5Cu (SAC 305) with the surface finish of copper substrate. The copper substrate surface finish was deposited by the electroless nickel. The work focuses on the formation of the microstructure after the corrosion test. On the other hand, this research involves the investigation of corrosion effect on the joining of the solder ball and the surface finish of copper substrate. The different corrosion test duration were applied. In this research also some characterization tools were used including image analyzer and scanning electron microscope (SEM) in order to determine the structure of the joining of solder ball formation.

1.5 STRUCTURE OF THESIS

This thesis consists of five chapters. Chapter one is an introduction in which problem statement, objectives of the research and scope of work are presented. The second chapter covers the literature review which includes printed circuit board, surface finishes, solder bump process and soldering technique. In addition, it also includes topics on the intermetallic compound formation at the interface of the solder joint and the environmental corrosion behavior that usually happened in electronic industry. In chapter three, the detailed experimental methodology followed in this research in order to achieve the objectives of the projects is described. In chapter four, result and discussion, all experimental results obtained are presented with the supportive explanation. Finally, in chapter five, a set of conclusions are drawn based on the findings throughout the research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this literature review is to establish a theoretical framework regarding the effect of corrosion on printed circuit board. This literature review is also an evidence to support the research topic to make easier to understand and to complete the project later on. The journals, conference papers, technical report and other useful resources will be including by summarize in this literature review section.

2.2 PRINTED CIRCUIT BOARD (PCB)

PCB form the electrical and mechanical connection between electrical components in the complex circuit of modern electronic designs. PCB not only interconnect with components through conductor routed through the board with traces and vias, but it also provide effective electrical insulation between conductors of different potentials and in different circuit nodes (Daren, 2004). In PCB, there are traces that electrically connect the various connectors and components to each other. Solder is the metal that makes the electrical connections between the surface of the PCB and the electronic components. Being metal, solder also serves as a strong mechanical adhesive.

Before the advent of the PCB circuits were constructed through a laborious process of point-to-point wiring. This led to frequent failures at wire junctions and short circuits when wire insulation began to age and crack. There are three major types of PCB construction: single-sided, double-sided, and multi-layered. Single-sided boards have the components on one side of the substrate. When the number of components becomes too much for a single-sided board, a double-sided board may be used.

2.2.1 Manufacturing Process PCB

PCB processing and assembly are done in an extremely clean environment where the air and components can be kept free of contamination. Most electronic manufacturers have their own proprietary processes, but the following steps might typically be used to make a two-sided printed circuit board (Pritchard, 1979)

(i) Generated from the design files and create an exact film representation of the design. Then, create one film per layer.

(ii) Shear raw material. Industry standard 0.059" thick, copper clad, two sides. Panels will be sheared to accommodate many boards.

(iii) Drill holes by using NC machines and carbide drills.

(iv) Apply thin copper deposit in holes barrels.

(v) Apply image. Apply photo sensitive dry film (plate resist) to panel. Use light source and film to expose panel. Develop selected areas from panel.

(vi) Electrochemical process to build copper in the holes and on the trace area. Apply tin to surface.

(vii) Remove dry film, and then etch exposed copper. The tin protects the copper circuitry from being etched.

(viii) Apply solder mask area to entire board with the exception of solder pads.

(ix) Apply solder to pads by immersing into tank of solder. Hot air knives level the solder when removed from the tank.

(x) Apply white letter marking using screen printing process.

(xi) Route the perimeter of the board using NC equipment.

2.3 SURFACE FINISH

Most of the PCB have surface finishes on their surface due to its improved electrical performance. However, if they are left unprotected, the copper will oxidize and deteriorate. It quickly forms a robust, chemically stable and electrically insulative oxide that creates a connection challenge once it exposed to air. Therefore, surface finish technologies have been developed and are applied to PCB to prevent oxidation of exposed copper on the board, thus ensuring a solderable surface when components are added at a later processing stage. The ideal surface finish would exhibit characteristics that listed below (Jose, 2002):

(i) The surface finish should be flat and uniform (planar) to allow for good lead connection and uniform component placement.

(ii) The surface finish should be environmentally friendly. It should not contaminate the environment during mining, manufacturing, assembly and post product life disposal.

(iii) The finish is compatible with standard assembly process that are proven and well used on today's various assembly lines.

(iv) The surface finish should have an extended shelf life and should not require special storage control to keep from oxidizing or contaminating the finish.

(v) The surface finish should promote good solderability. It should process during assembly just as HASL and have good solder reliability.

(vi) The finish process should generate the highest yield. It should not introduce the PCB to excessive and volatile process, handling or thermal excursions.

However, the ideal surface finish does not exist. Every finish has reliability concerns or fabrication problems. So the goal is to pick out the most important aspects of the surface finish and choose the alternative that best meets the assembly requirements. The following are the most common process variables of concern at assembly (Grainger, 1989):

(i) Component type and placement method

(ii) Solder paste type and application (if applicable)

(iii) Fusing method

(iv) Possible exposure of each board type to a variety of assembly processes

(v) Multiple thermal exposures

(vi) Post cleaning (if applicable)

Less common considerations include the elimination of CFCs and the possible exclusion of leaded solders, solder paste, and flux at assembly. There are various technologies used for surface finishing nowadays. The predominant PCB surface finishes include:

(i) Hot Air Solder Level (HASL)

(ii) Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG)

(iii) Organic Solderability Preservative (OSP)

(iv) Immersion Silver (ImAg)

(v) Electroless Nickel/Immersion gold (ENIG)

(vi) Immersion Tin (ImSn)

2.3.1 Hot Air Solder Leveling (HASL)

In Figure 2.1, HASL is the standard surface finish available in the electronic industry. Basically, a thin coating of solder is applied on the exposed copper by immersed the panel into a molten solder bath. After that, the panel surface passing through the hot air. However, as the miniaturization of electronic package further continued, the HASL surface finish is not flat or coplanar enough for fine pitch pads. Figure 2.1 is the cross section of the HASL surface finish (Clyde, 2001). The excess solder is then blown from the board by an air knife, leaving a thin, protective layer of solder on the exposed circuitry. The HASL process from the other alternatives in that it does not rely on a chemical process to apply the final surface finish. However, this process has been increasingly under scrutiny due to environmental and safety issues (hazardous waste, lead exposure etc), technological limitations (fine-pitch device assembly) and equipment maintenance cost.

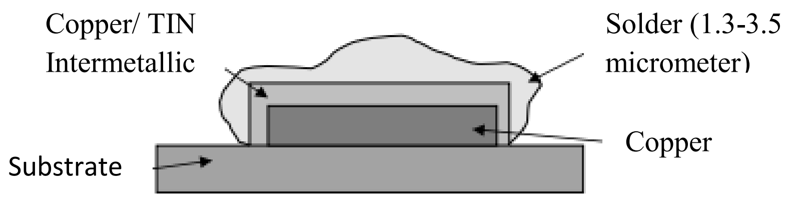

Figure 2.1: Schematic of HASL Surface Finishing

Source : Clyde 2001

2.3.2 Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG)

ENEPIG is the universal surface finish where it has the similar function with ENIG. In this surface finish, an electroless nickel layer is deposited on the copper surface. Then a palladium layer is coated on top of the nickel layer. Lastly, immersion gold is topped as a final layer. The function of the palladium is to prevent corrosion during immersion reaction. The palladium and gold will dissolve in the solder during soldering and forms a nickel/ tin inter metallic. However, the limitation of this surface finish is additional cost which leads to higher packaging fabrication cost (Clyde, 2001). The ENEPIG surface finish is illustrated in Figure 2.2.

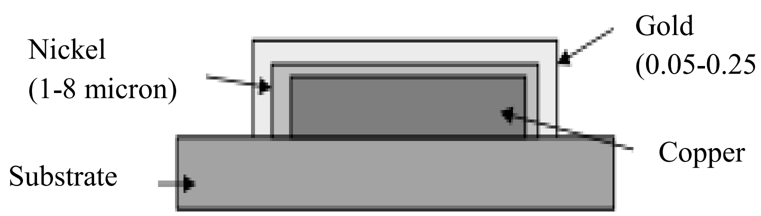

Figure 2.2: Schematic of Ni/Pd/Au Surface Finish

Source: Clyde 2001

2.3.3 Organic Solderability Preservative (OSP)

By referring the Figure 2.3, OSP is a thin organic compound coats the copper surface. This organic coating preserves the copper surface from oxidation until it is soldered. Benzotriazoles and imidazoles are most widely used preservatives and both are nitrogen- bearing organic compounds. Both compounds have the ability to complex with the exposed copper surface and it does not adsorb to the laminate or solder mask. The organic solderability preservative (OSP) is illustrated.

Benzotriazoles form a thin monomolecular layer to protect the copper until it is exposed to a single thermal excursion at assembly. Where else, Imidazoles form a thicker coating and survive multiple thermal excursions at assembly. Nevertheless, the transparent and colorless coating has caused some inspection difficulties after processing. It also requires thicker coating for electrical testing purpose due to its non-conductive characteristic. Besides that, OSP material especially Imidazoles need more aggressive flux after first and second thermal excursions (Clyde, 2001).

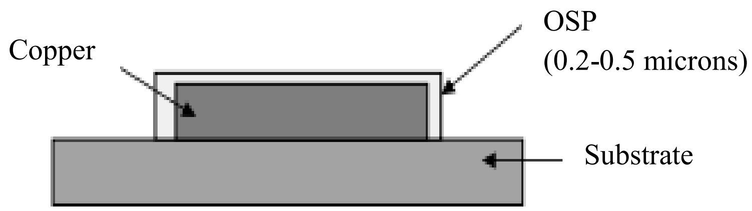

Figure 2.3: Schematic of OSP Surface Finish

Source: Clyde 2001

2.3.4 Immersion Silver (ImAg)

ImAg is an ideal surface finish for soldering where it provides a thin (0.1 to 0.65um), solid silver deposit incorporating an organic and the organic seals the surface to allow for extended shelf life. During assembly the silver will dissolves into the solder and form copper/ tin intermetallic solder joint which similar to HASL and OSP. Silver offers good coplanarity and solderable surface compare to HASL and it is easy for inspection since its appearance is visible.

It is a potential replacement for HASL due to its lead free coating where it fulfills the ‘greener’ environmental requirement. However, silver migration in electronic environments is a concern due to its property to form wafer soluble salts when exposed to moisture and electrical bias (Clyde, 2001). The ImAg surface finish is illustrated in Figure 2.4.

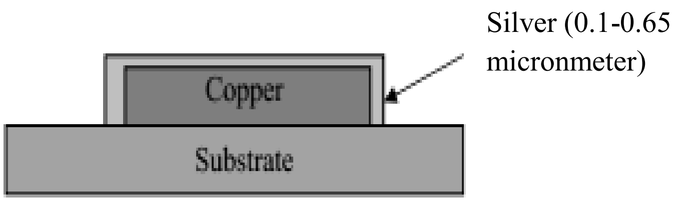

Figure 2.4: Schematic of Immersion Silver

Source: Clyde 2001

2.3.5 Electroless Nickel/Immersion Gold (ENIG)

ENIG is a surface finish that consists of a thick layer of electroless nickel on the top of copper surface and a thin layer of gold on top of nickel surface as shown in Figure 2.5. Characteristic of nickel such as hardness, wear resistance, solderability and uniformly make the PWB more durable while gold prevents oxidation of the nickel which is highly active. ENIG finishes can typically withstand as many as six or more thermal excursions (heating cycles) during assembly without losing solderability. Palladium salt in an acidic solution had been used as the catalyst for ENIG. Palladium ions are deposited onto the surface of the PWB in displacement reaction. The present of this palladium makes the reducing agent to provide electrons to the positivity charged nickel ions during electroless nickel process and causing the reduction of the nickel and the deposition of element nickel onto the exposed palladium catalyst (Parquet and Spence, 1996).

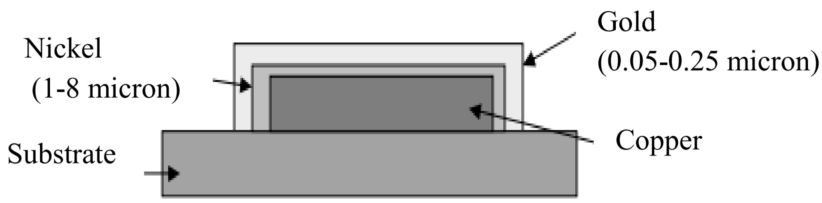

Figure 2.5: Schematic of ENIG Surface Finish

Source: Parquet and Spence 1996

2.3.6 Immersion Tin (ImSn)

ImSn is a good solderable surface where it is deposited directly on the copper surface by chemical displacement reaction. It provides a dense uniform tin with organic coating and forms a standard copper/ tin intermetallic solder joint. Good coplanarity and lead free characteristic allow it to become one of the option as HASL replacement especially for backplane panel application which assembled by pin insertion.

Nevertheless, there are few concerns which limit the growth of this surface finish. One of the main concerns is tin whiskers where it is hairline and mono-crystals that develop and grow as a result of internal stress (mechanical, thermal, and other forms) increase the possibility of electrical short. The growth of copper/ tin intermetallic also limiting the shelf life of the surface and it can further reduce as the reaction accelerates under excessive temperature and humidity condition (Clyde, 2001). ImSn surface finish is illustrated in Figure 2.6.

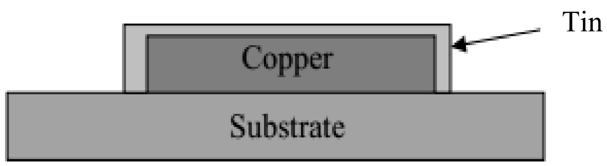

Figure 2.6: Schematic of ImSn Surface Finish

Source: Clyde 2001

2.3.7 Electroless Plating

Electroless plating is the chemical deposition of a metal coating onto an object using chemical reactions rather than electricity. The basic ingredients in an electroless plating solution are a source metal (usually a salt), a reducer, a complexing agent to hold the metal in solution, and various buffers and other chemicals designed to maintain bath stability and increase bath life. Copper and nickel electroless plating commonly are used for printed circuit boards (Mallory and Hadju, 1990).

2.3.8 Immersion Plating

Immersion plating is a similar process in that it uses a chemical reaction to apply the coating. However, the difference is that the reaction is caused by the metal substrate rather than by mixing two chemicals into the plating bath. This process produces a thin metal deposit by chemical displacement, commonly zinc or silver. Immersion plating baths are usually formulations of metal salts, alkalis, and complexing agents (e.g., lactic, glycolic, or malic acids salts). Electroless plating and immersion plating commonly generate more waste than other plating techniques, but individual facilities vary significantly in efficiency (Mallory and Hadju, 1990).

2.3.9 Electroplating

Electroplating is achieved by passing an electric current through a solution containing dissolved metal ions and the metal object to be plated. The metal object serves as the cathode in an electrochemical cell, attracting ions from the solution. Ferrous and non-ferrous metal objects are plated with a variety of metals including aluminum, brass, bronze, cadmium, copper, chromium, gold, iron, lead, nickel, platinum, silver, tin, and zinc. The process is regulated by controlling a variety of parameters including voltage and amperage, temperature, residence times, and purity of bath solutions.

Plating baths are almost always aqueous solutions, therefore, only those metals that can be reduced in aqueous solutions of their salts can be electrodeposited. Plating operations are typically batch operations in which metal objects are dipped into a series of baths containing various reagents for achieving the required surface characteristics. A typical plating sequence involves various phases of cleaning, rinsing, stripping, and plating. Electroless plating uses similar steps but involves the deposition of metal on metallic or non-metallic surfaces without the use of external electrical energy (Mallory and Hadju, 1990).

2.4 SOLDERING PROCESS

Soldering is defined as a process that is used to bond similar or dissimilar materials by melting a filler metal or alloy that is placed between the components being joined. The filler metal, or rather called the solders, must have a much lower melting point compare with the materials being joined. During the process, the molten solders wet the materials in contact with in, forming metallurgical bond by diffusion, dissolving, or alloying with the basis metal (Clyde, 2001). The base metals being joined are usually aluminium or copper. Meanwhile, there are various types of solders being used in the industry in Table 2.1.

Table 2.1: Common Solder Material

Solder	Characteristic	Application
Tin-Silver	Non-toxic but expensive. Good high temperature properties.	Used for soldering medical or high precision instruments. High temperature applications
Tin-Lead	Good process characteristics and the best understood solders	General purpose and the most widely used solders
Tin-Antimony	Non-toxic. Good high temperature properties. Better electrical conductivity and strength than tin-lead solders. Good wetting.	High temperature and food industry applications
Indium	Deforms easily	Low temperature soldering, wets glass
Bismuth	Deforms easily. Needs Aggressive fluxes	Low temperature soldering
Cadmium-Silver	Toxic. Good tensile strength	High temperature applications
Lead-Silver	Good high temperature properties, good fatigue strength. Medium or low flow properties	High temperature applications
Cadmium-Zinc	Toxic	Soldering aluminum

Source : eFunda (2005)

Therefore, choosing the right solders become the primary concern in the electronic industry. The decision to use a particular material is largely based on its properties such as: ductility, heat conductivity, thermal expansion, electrical resistance, tensile strength, toxic, wettability, and most importantly, the cost.